Accelerated Insertion of Materials – Industrial Perspectives on Polymer Matrix Composites

Composites at Lake Louise

Structural Composites Keynote Address

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AIM-C Alignment Tool

The objective of the AIM-C Program is to provide concepts, an approach, and tools that can accelerate the insertion of composite materials into DoD systems.

AIM-C Will Accomplish This Three Ways

Methodology - ***We will evaluate the historical roadblocks to effective implementation of composites and offer a process or protocol to eliminate these roadblocks and a strategy to expand the use of the systems and processes developed.***

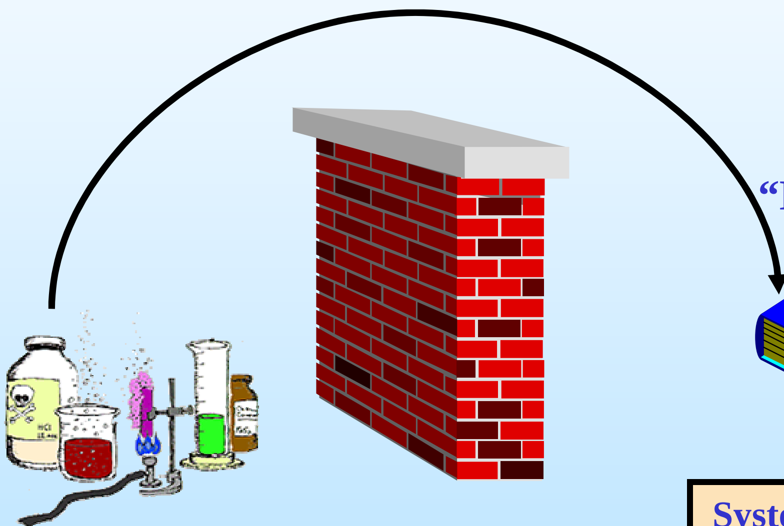
Product Development - ***We will develop a software tool, resident and accessible through the Internet that will allow rapid evaluation of composite materials for various applications.***

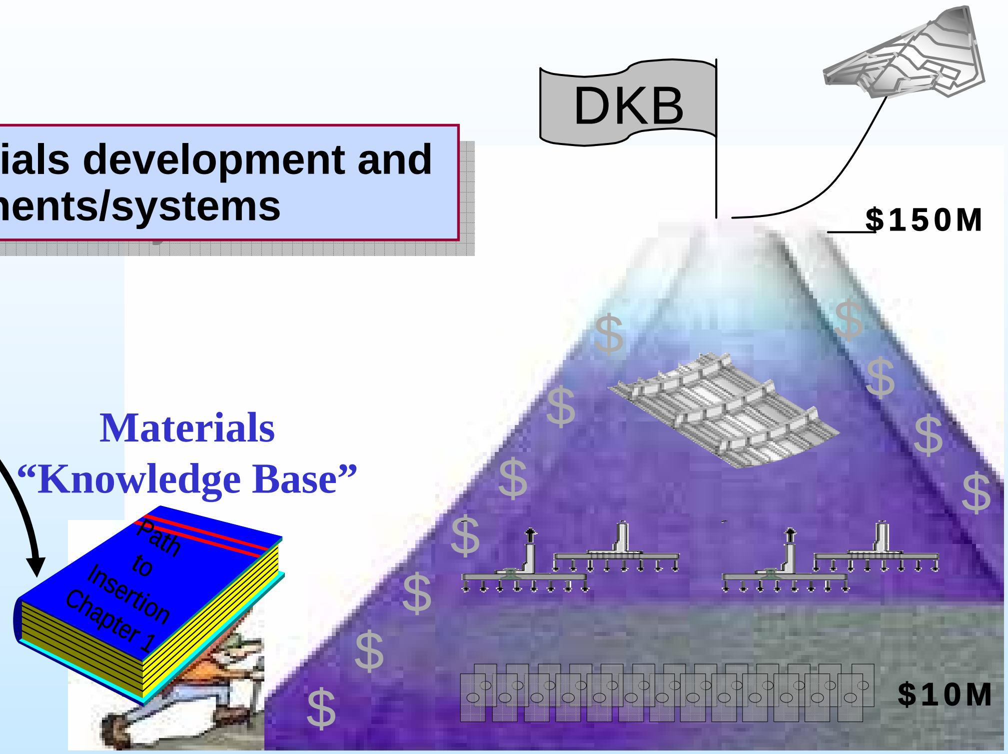
Demonstration/Validation - ***We will provide a mechanism for acceptance by primary users of the system and validation by those responsible for certification of the applications in which the new materials may be used.***

Tasks in Phase 1 are directed toward Transition.

Technical Motivation

Significant disconnect between materials development and the design/use of materials in components/systems





Materials Development

- Highly Empirical
- Testing Independent of Use
- Existing Models Unlinked
- No Link to Designer Needs

System Design: Needs …..
Materials "Knowledge Base" & Confidence In

- Validation of Critical Properties
- Scale-up of Design and Process(es)
- Manufacture of Parts and Components
- Assessment of Costs
- Predictable Reliability and Life Expectancy

To Establish a Designer Knowledge Base (DKB)
… In a Fixed Insertion Window of Time

DESIGN TEAM'S NEEDS

Requirements are Multi-Disciplined

Structural

- Strength and Stiffness
- Weight
- Service Environment
  - Temperature
  - Moisture
  - Acoustic
  - Chemical
- Fatigue and Corrosion Resistant
- Loads & Allowables
- Certification

Manufacturing

- Recurring Cost, Cycle Time, and Quality
- Use Common Mfg. Equipment and Tooling
- Process Control
- Inspectable
- Machinable
- Automatable
- Impact on Assembly

Supportability

- O&S Cost and Readiness
- Damage Tolerance
- Inspectable on Aircraft
- Repairable
- Maintainable
  - Accessibility
  - Depaint/Repaint
  - Reseal
  - Corrosion Removal
- Logistical Impact

Material & Processes

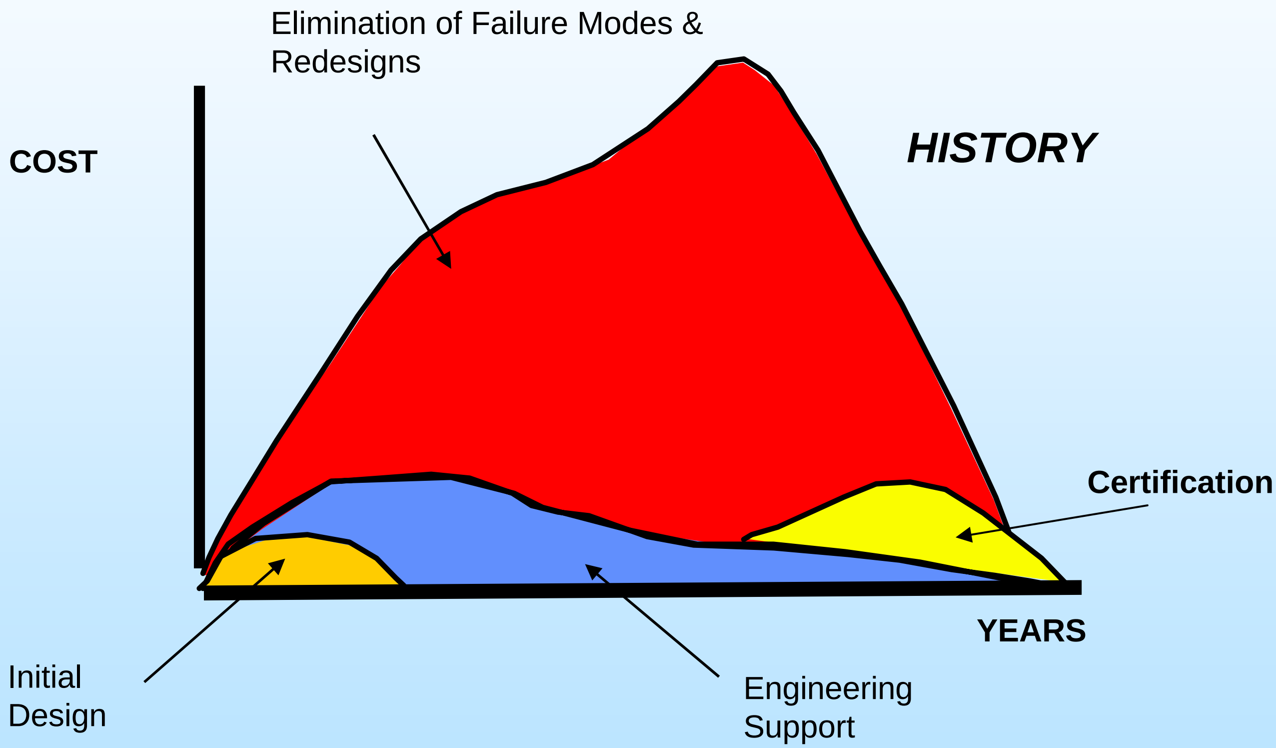
- Development Cost
- Feasible Processing Temperature and Pressure
- Process Limitations
- Safety/Environmental Impact
- Useful Product Forms
- Raw Material Cost
- Availability
- Consistency

Miscellaneous

- Observables
- EMI/Lightning Strike
- Supplier Base
- Applications History
- Certification Status
  - USN
  - USAF
  - ARMY
  - FAA

Background: What is the Issue?

Often, our development time and money is spent on fixing problems because we were not correct with the material, process or design characterization.



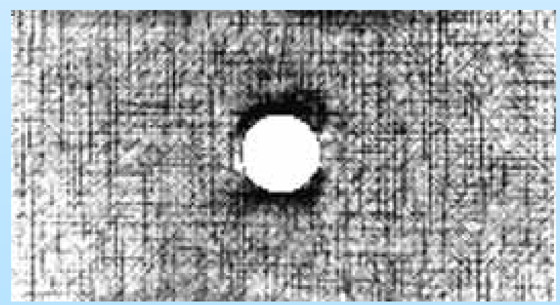
Development Cycle for a Typical Hardware Insertion

Implications of the current scenario:

Risk Adversity – Stay with known materials and concepts

Among the Top Problems to Accelerated Insertion:

Scale Up
End of Life Properties
Part Geometry
Unplanned Rework
Transition, Support Knowledge



What is AIM-C?

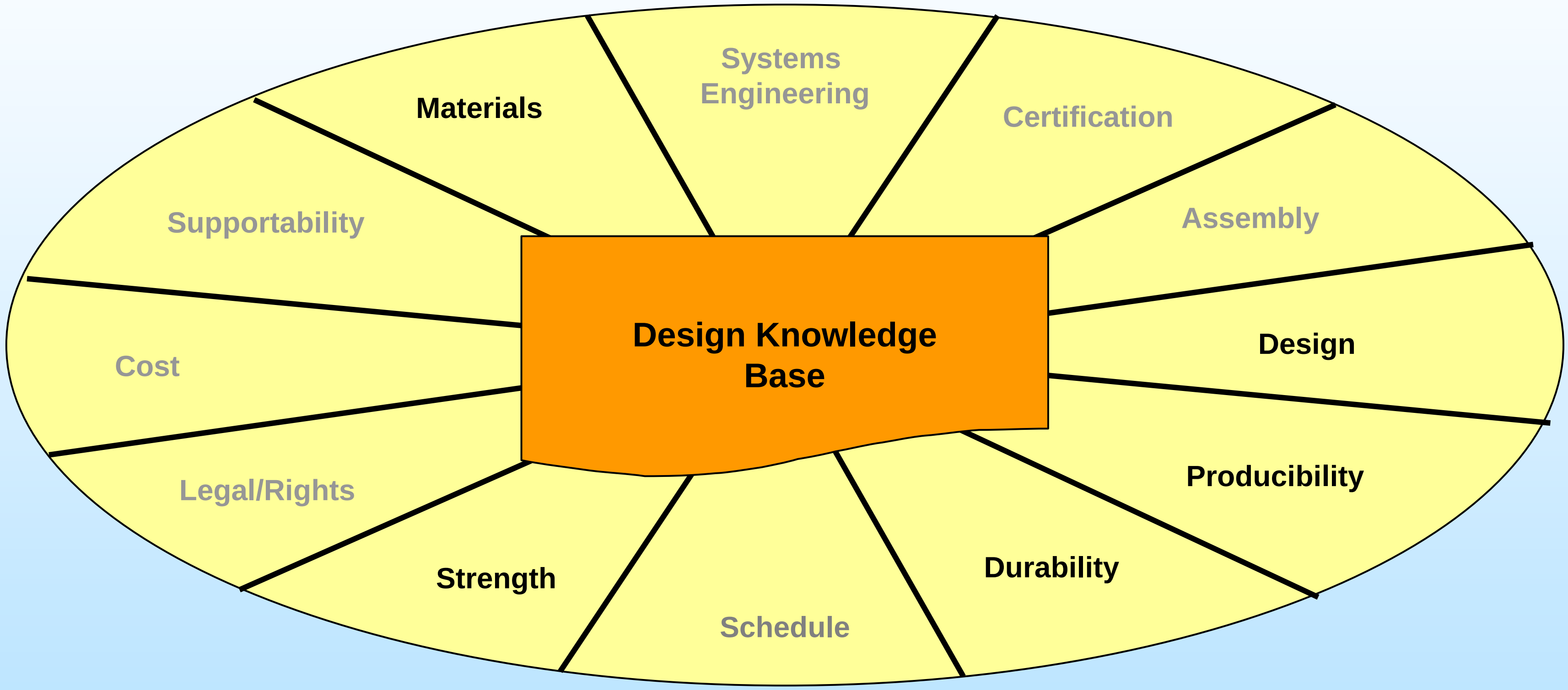
AIM-C is a <u>methodology</u> for accelerated insertion of materials into defense structures at reduced costs.

This methodology develops a design knowledge database that links what is known about a material system to what is needed in order to qualify its application to an application that meets certification requirements

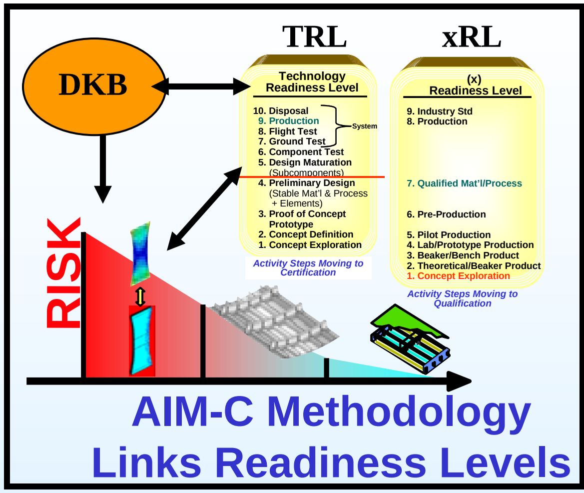
It allows rapid identification of which applications are too risky and which are not.

It uses verified analysis methods, existing test data, and lessons learned from previous experience to minimize the amount of data required to insert new materials into a system with confidence

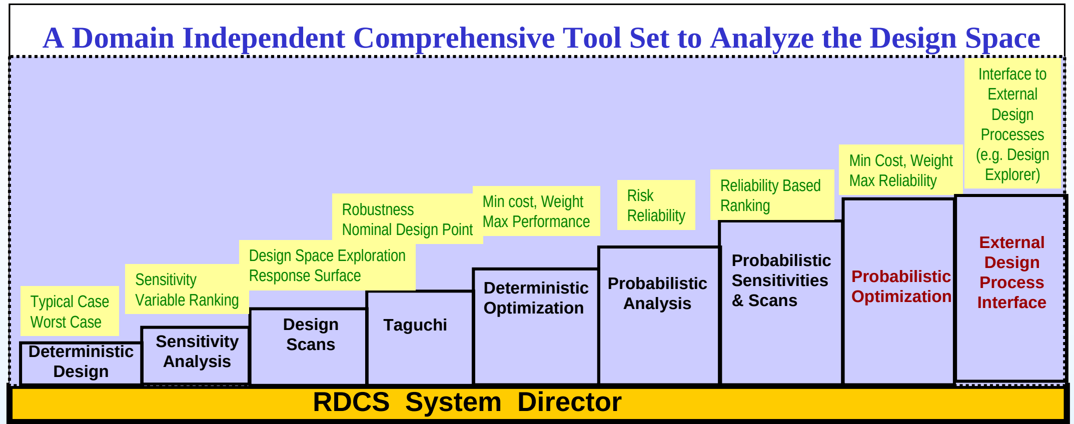
The AIM-C System Uses the Integrated Product Definition Process to Produce the Design Knowledge Base



Each function contributes and receives knowledge



Assessment

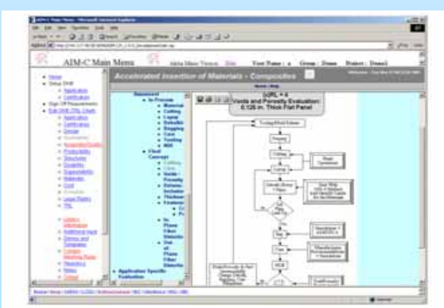


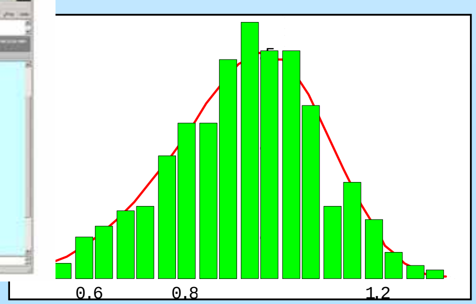
Computational Tools

The AIM-C Methodology

Knowledge Management & Feature Based Studies

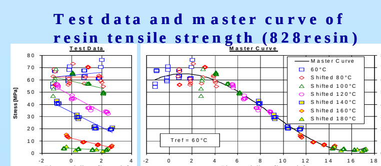
Encoded Heuristics

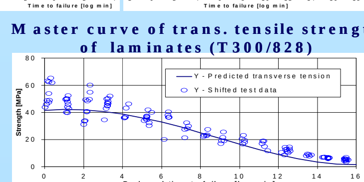




Producibility

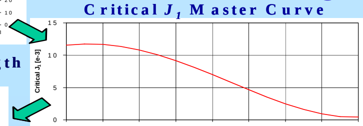
Analysis and Test





Strain Invariant Failure Theory Coupled with Accelerated Testing

Critical J_1 Master Curve



Reduced time to failure [log min]
= f(time and temperature)

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Assessment: Thorough Consideration of Each Category

- Application
- Certification
- Materials
- Producibility
  - Processing/Fabrication
- Structures
- Durability
- Supportability
- Design
- Intellectual Rights/Legal
- Cost
- Schedule
- Assembly

Assessment: Technology Readiness Levels

• Defining <u>all</u> the Questions and Measuring Progress

TRL	1	2	3	4	5	6	7	8
Application Risk	Very High	High	High - Med	Med - High	Medium	Med - Low	Low	Low - Very Low
Application Maturity		Concept Defintion	Proof of Concept	Preliminary Design	Design Maturation	Component Testing	Ground Test	Flight Test
Certification	Certification Requirements Documented	Certification Plan Documented	Certification Plan Approved	Preliminary Design Allowables	Subcomponent Testing	Full Scale Component Testing	Full Scale Airframe Tests	Flight Test
Design	Concept Exploration/ Potenital Benefits Predicted	Concept Defintion/ Applications Revised by Lamina Data (Coupons)	Applications Revised by Laminate Data (Coupons)/ Design Closure	Applications Revised by Assy Detail Test Data (Elements)/ Preliminary Design	Applications Revised by Subcompnent Test Data/ Design Maturation	Applications Revised by Component Test Data/ Ground Test Plan	Applications Revised by Airframe Ground Tests/ Flight Test Plan	Production Plan
Assembly	Assembly Concept	Assembly Plan Defintion	Key Assembly Detail Defintions	Key Assembly Details Tested	Subcomponents Assembled	Components Assembled	Airframe Assembled	Flight Vehicles Assembled
Structures Maturity	Preliminary Properties-Characteristics	Initial Properties Verified by Test	Design Properties Developed	Preliminary Design Allowables	B-Basis Design Allowables	A-Basis Design Allowables		
Materials Maturity	Lab-Prototype Materials	Pilot Production Materials	Pre-Production Materials	Production Materials/ Material Specs			EMD Material Supplied	LRIP Material Supplied
Fabrication Maturity	Unfeatured-Panel Fabrication	Feature Based Generic Small/Subscale Parts Fabricated	Property-Fab Relationships Tested/ Target Application Pilot Production of Generic Full Size Parts	Process Specs/ Effects of Fab Variations Tested/ Elements Fab'd/ Production Representative Parts Fab'd	Subcompnents Fab'd	Full Scale Components Fabricated	EMD Fabrication	Low Rate Initial Production (LRIP)
Cost Benefits Maturity	Cost Benefit Elements ID'd & Projected	ROM Cost Benefit Analysis	Cost Benefit Analysis Reflect Size Lessons Learned	Cost Benefit Analysis Reflect Element and Production Representative Part Lessons Learned	Cost Benefit Anlysis Reflect Subcomponent Fab & Assembly Lessons Learned	Cost Benefit Anlysis Reflect Component Fab & Assembly Lessons Learned	Cost Benefit Anlysis Reflect EMD Lessons Learned	Cost Benefit Anlysis Reflect LRIP Lessons Learned
Supportability	Repair Items/Areas Identified	Repair Materials & Processes Identified	Repair Materials & Processes Documented	Fab Repairs Identified	Fab Repair Trials/ Subcomponent Repairs	Component Repairs	Production Repairs Identified	Flight Qualified Reapirs Documented
Intellectual Rights	Concept Documentation	Patent Disclosure Filed	Proprietary Rights Agreements	Data Sharing Rights	Vendor Agreements	Material and Fabrication Contracts	Production Rate Contracts	Vendor Requal Agreements

<u>**Concept Definition**</u>
- **Application Definition, Loads, Environment**
- **Concept Refinement**

<u>**Concept Definition/Applications Revised By Lamina Data**</u>
- **Design/Geometry Parameter Studies**
- **Heuristics, Simulation, Test**

<u>Assembly Concept</u>
- Effect of Assembly on Performance
- Effects of Defects

<u>Production Materials/Materials Specs</u>
- Material Property Studies

<u>Cost Benefit Elements ID'd And Projected</u>
- Performance Data for Trades

<u>Property-Fab Relationships Tested/ Target Application Pilot Production of Generic full Size Parts</u>
- Effect of cure/tooling on Performance

<u>**Preliminary Properties-Characteristics**</u>
- **Analysis/Test-Generated Design Values**
- **Effects of variability**

Assessment: Tracking Conformance

AIM-C Technology Readiness Summary

Codes :	YES (done)	NO (not done)	In-Work	Problem	N/A

TRL	1	2	3	4	5	6	7	8	9	10
Application Risk	Very High	High	High - Med	Med - High	Medium	Med - Low	Low	Low - Very Low	Very Low	Negligible
Application Maturity	Concept Exploration	Concept Defintion	Proof of Concept	Preliminary Design	Design Maturation	Component Testing	Ground Test	Flight Test	Production	Recycle or Dispose
Certification	Certification Elements Documented	Certification Plan Documented	Certification Plan Approved	Preliminary Design Values	Subcomponent Testing	Full Scale Component Testing	Full Scale Airframe Tests	Flight Test	Production Approval	Disposal Plan Approval
Design	Concept Exploration/ Potenital Benefits Predicted	Concept Defintion/ Applications Revised by Lamina Data (Coupons)	Applications Revised by Laminate Data (Coupons)/ Design Closure	Applications Revised by Assy Detail Test Data (Elements)/ Preliminary Design	Applications Revised by Subcompnent Test Data/ Design Maturation	Applications Revised by Component Test Data/ Ground Test Plan	Applications Revised by Airframe Ground Tests/ Flight Test Plan	Production Plan	Production Support	Disposal Support
Assembly	Assembly Concept	Assembly Plan Defintion	Key Assembly Detail Defintions	Key Assembly Details Tested	Subcomponents Assembled	Components Assembled	Airframe Assembled	Flight Vehicles Assembled	Production	Disassembly for Disposal
Structures Maturity	Preliminary Properties-Characteristics	Initial Properties Verified by Test	Design Properties Developed	Preliminary Design Values	B-Basis Design Allowables	A-Basis Design Allowables	-	-	Flight Tracking/ Production Spport/ Fleet Support	Retirement for Cause
Materials Maturity	Lab-Prototype Materials	Pilot Production Materials	Pre-Production Materials	Production Materials/ Material Specs	-	-	EMD Material Supplied	LRIP Material Supplied	Production Material Supplied	Support for Recycle or Disposal Decisions
Fabrication Maturity	Unfeatured-Panel Fabrication	Feature Based Generic Small/Subscale Parts Fabricated	Property-Fab Relationships Tested/ Target Application Pilot Production of Generic Full Size Parts	Process Specs/ Effects of Fab Variations Tested/ Elements Fab'd/ Production Representative Parts Fab'd	Subcompnents Fab'd	Full Scale Components Fabricated	EMD Fabrication	Low Rate Initial Production (LRIP)	Production	Recycle or Disposal
Cost Benefits Maturity	Cost Benefit Elements ID'd & Projected	ROM Cost Benefit Analysis	Cost Benefit Analysis Reflect Size Lessons Learned	Cost Benefit Analysis Reflect Element and Production Representative Part Lessons Learned	Cost Benefit Anlysis Reflect Subcomponent Fab & Assembly Lessons Learned	Cost Benefit Anlysis Reflect Component Fab & Assembly Lessons Learned	Cost Benefit Anlysis Reflect EMD Lessons Learned	Cost Benefit Anlysis Reflect LRIP Lessons Learned	Cost Benefit Anlysis Reflect Production Lessons Learned	Cost Benefit Anlysis Reflect Disposal Lessons Learned
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Assessment Becomes a Requirements Flow Down and a Completion Roll Up

Technology Readiness Levels

Detail or "x" Readiness Levels

Exit Criteria

Worksheet

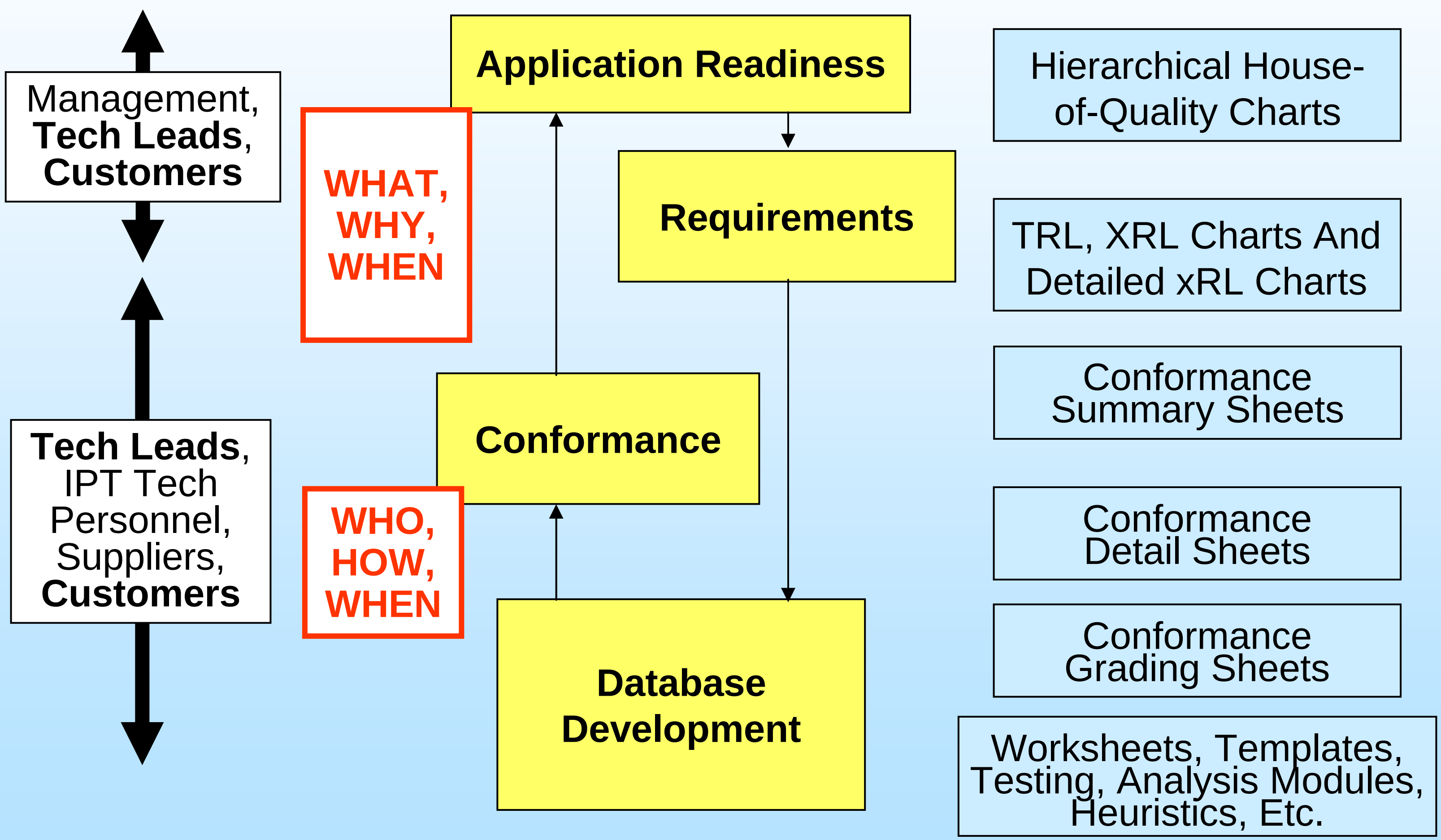
- Use of Prior Knowledge
- Recommended Analyses
- Recommended Tests
- Recommended Combination of Prior Knowledge / Analysis /Test

The Same Linkage Used To Flow Down Requirements Is Used to Roll Up Knowledge And Track Progress as Designer Knowledge is Gathered.

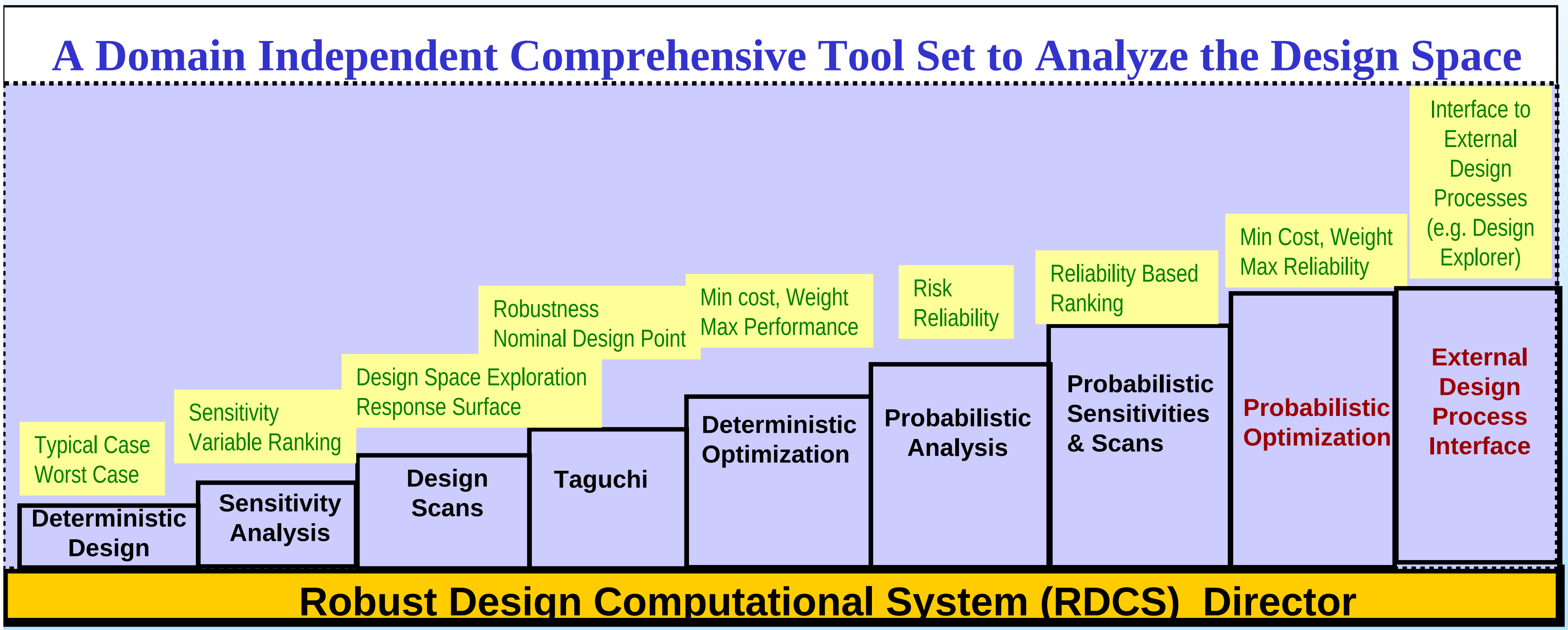
Integrated Product Team Chooses How To Meet Each Exit Criteria

Assessment Summary

Users/Participants ***Process Steps*** ***Tool Sets***



Computational Tools & Distributed Computing



Runs on Linux, HP, and Sun

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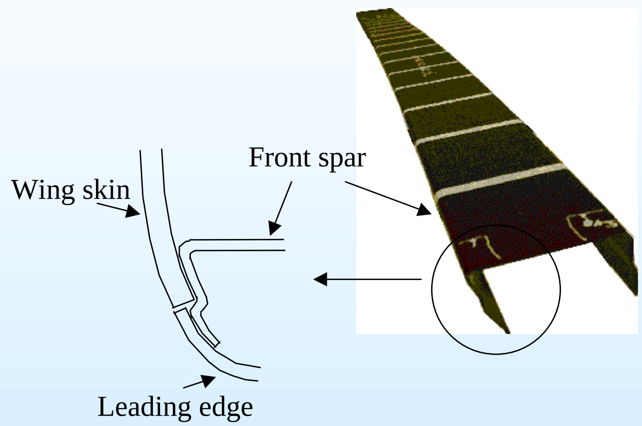
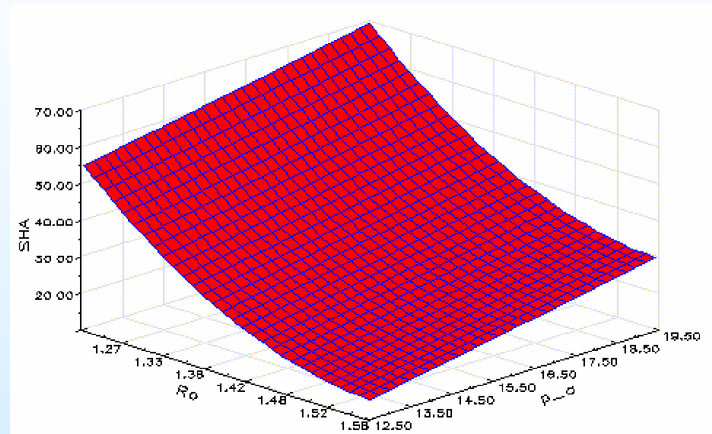
Computational Tools:
COMPRO* Software Integration with RDCS

2D FEM Cure Simulation of Wingtip Spar

767-400 Raked Wingtip Front Spar
DOE Sensitivity Analysis



RDCS Sensitivity Analysis Plus
Design Scan



Order of Magnitude Increase in Problem Solving Efficiency

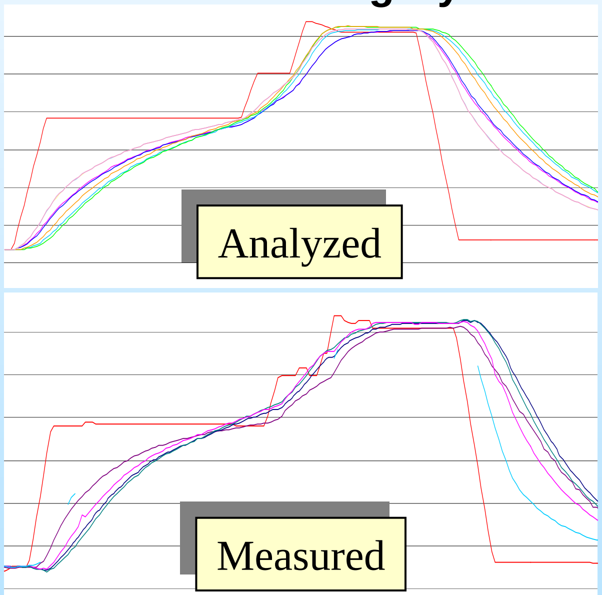
* Composites Processing (COMPRO) software is commercial software copyright protected by Convergent Manufacturing Technologies of British Columbia

B

Computational Tools: Process Design by Analysis

2D FEM Cure Simulation of a Thick Composite Laminate

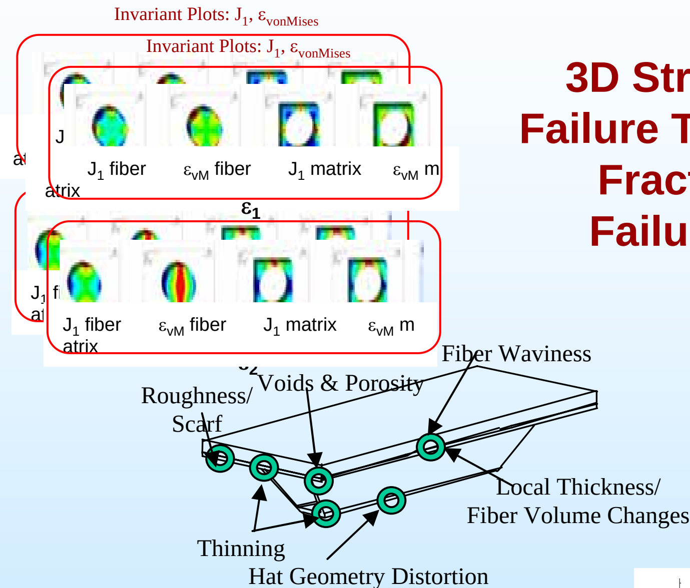
Processing Cycle



Analysis Yielded Robust Cure Cycle -- Verified by A Single Test
Original Plan Called For a Costly 6-Part Build Experimental Study

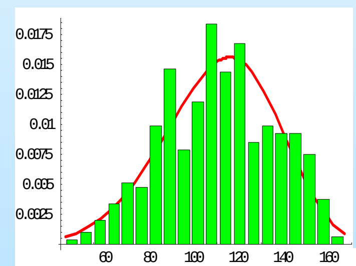
Analysis and Test Ties Across Functions: Structures Failure Prediction

- Use Physics-Based or Mechanistic Analysis Methods
- Link with Manufacturing Processes to allow Prediction of Real Component Properties
- Integrate with Statistical and Computational Methods; RDCS, Sensitivity Analysis
- Validate

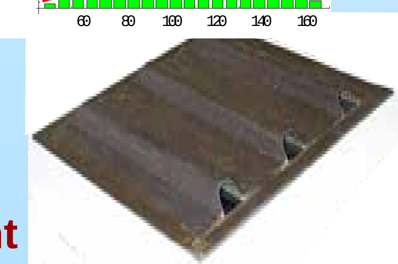


3D Strain Invariant Failure Theory (SIFT) & Fracture-Based Failure Theories

Effects of Defects & Residual Stress



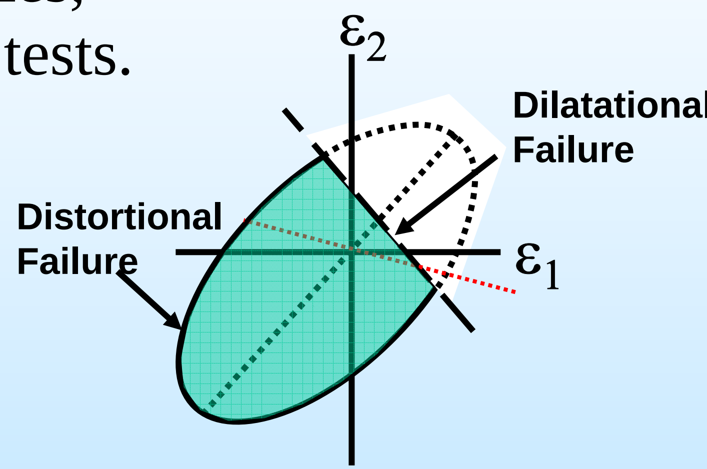
Parametric Statististical & Processing Variability

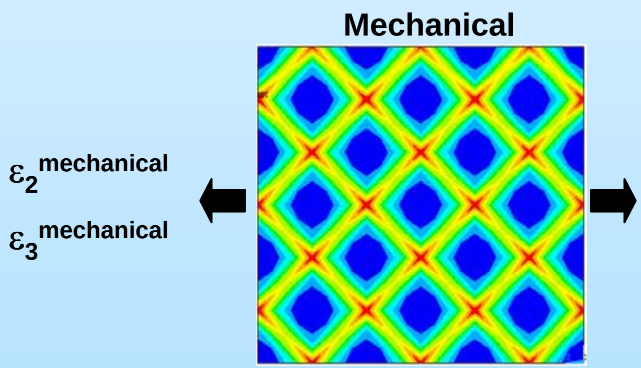


Reduced Amount of Testing for Component Certification

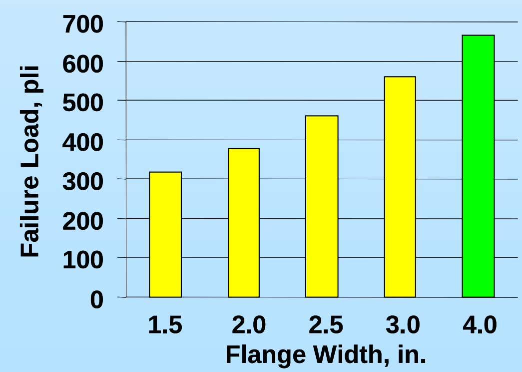
Analysis and Test Ties Across Scales

– Examples include SIFT and Advanced Fracture Methods
– Can Predict Complex Structures with arbitrary loading
– Use **only** Intrinsic Material Properties, obtained from simple, inexpensive tests.
– Predict Structural behavior and failure mode, not just failure load
– Take advantage of knowledge at constituent/lamina level





– Trend correctly with **all** variables



Knowledge Management and Feature Based Studies: Producibility*

Definition:

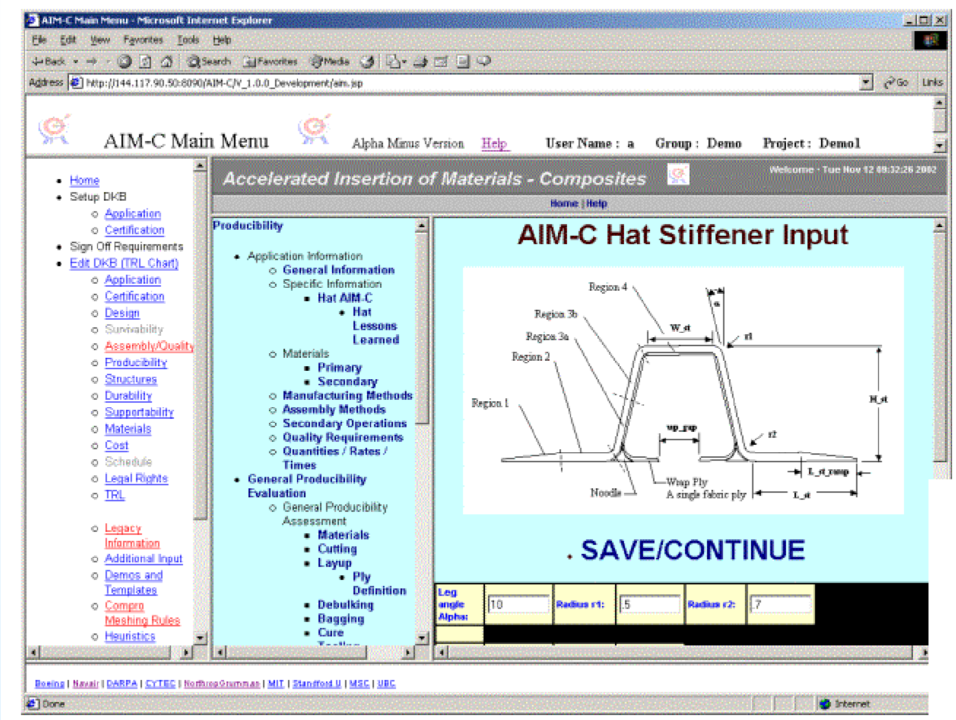
A Controller Module to Compare Requirements to Manufacturing Capabilities For Quality Components

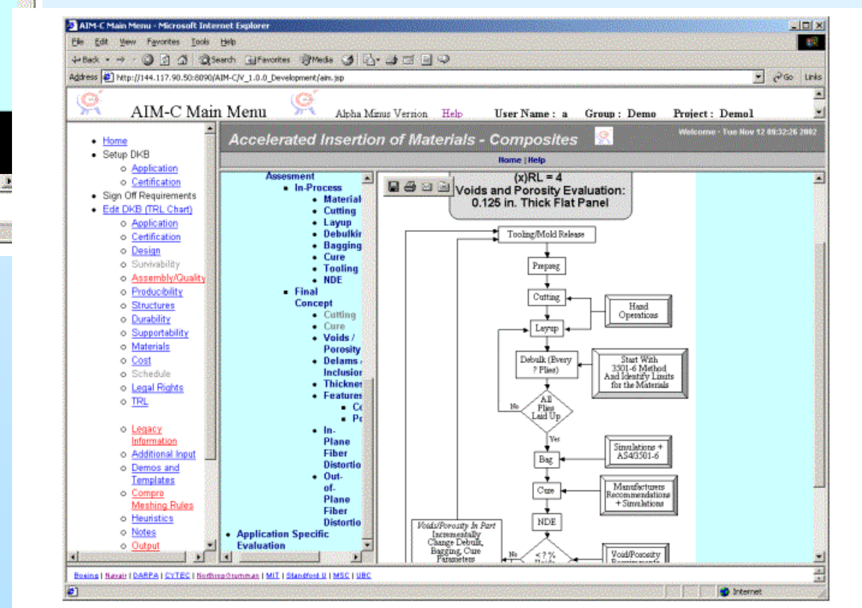
Corollaries:

- ***Can I Make It?***
- ***With What Degree of Success?***
- ***How Can I Make It?***
- ***By Which Manufacturing Sequence Should It Be Made?***

***Addresses scale up, part geometry, planned rework and avoidance of unplanned rework, provides for knowledge transfer.**

Producibility Module Interface





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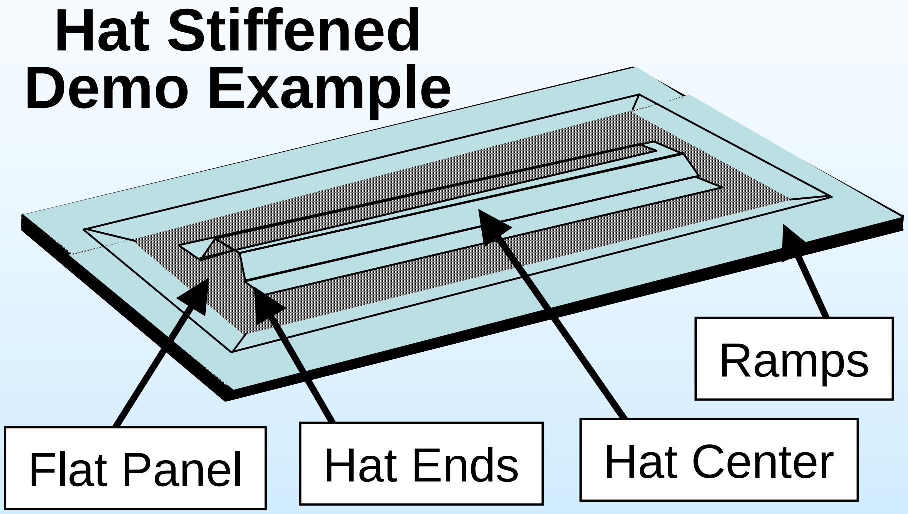
Knowledge Management and Feature Based Studies: Producibility



Feature Based Assessment Steps

1. Define Configuration
2. Identify Features/ Characteristics
3. Identify Defects Associated With Features/ Characteristics
4. Identify Tooling Options
5. Associate Defects to Tooling, Producibility and Material Areas
6. Quantify Defects Relative to Tooling, Producibility and Material Areas

Knowledge Management and Feature Based Studies

<u>Producibility Area:</u> Final Part Quality - Thickness

Application Info

- Minimum and Maximum Part Thicknesses
- Tolerances in Inches
- Design Per Ply Thickness
- Materials

Fiber

- Density

Resin

- Density

Prepreg

- FAW
- RAW/ Resin Content

<u>Materials Modules/Data Base</u>

- Averages/Means/Medians
- Standard Deviations
- Min
- Max

Producibility Module

Outputs

- Total Plies for Thinnest Part
- Total Plies for Thickest Part
- The Number of Plies Where Design Thickness Plus or Minus Tolerance is Exceeded With…
  - Average Material Thickness & Std Deviation
  - Minimum Material Thickness
  - Maximum Material Thickness

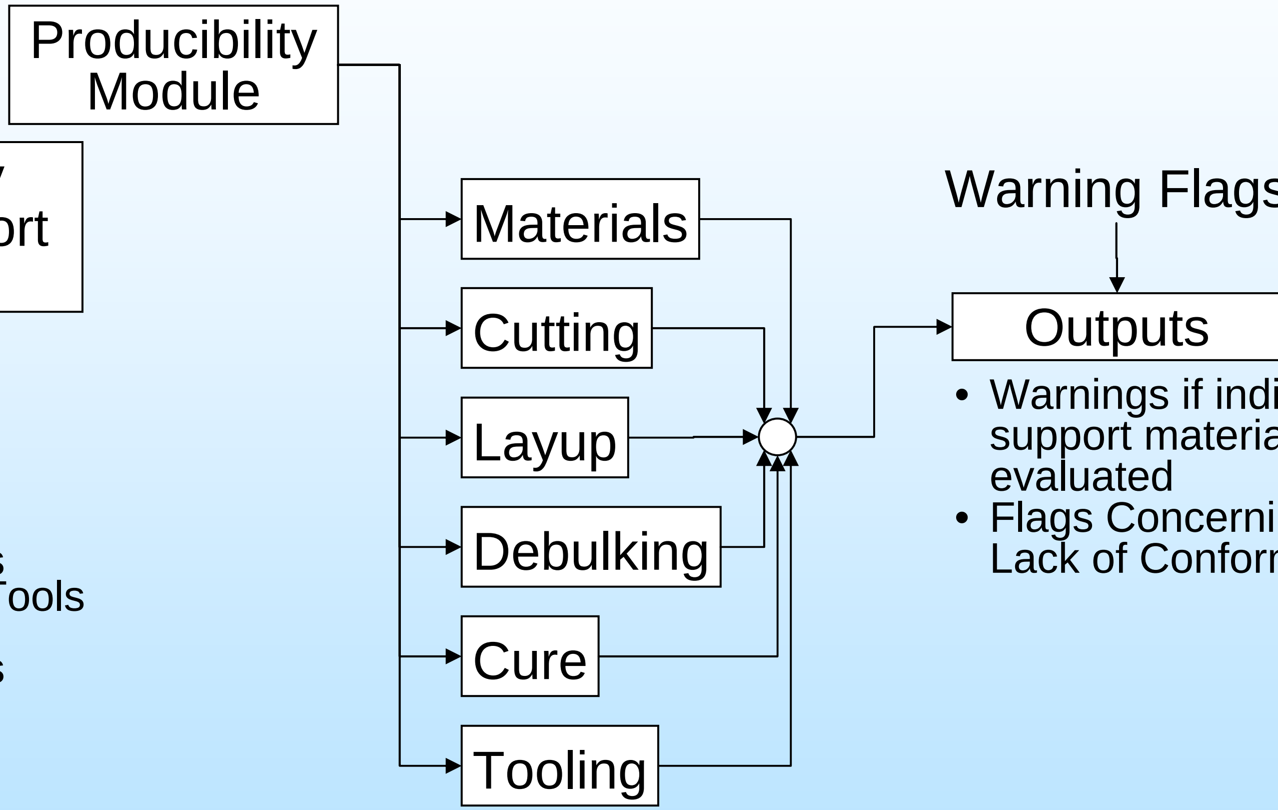
Knowledge Management and Feature Based Studies

Producibility Area: In-Process Quality – Producibility Operations

Final Part Quality – Inclusions & NDE

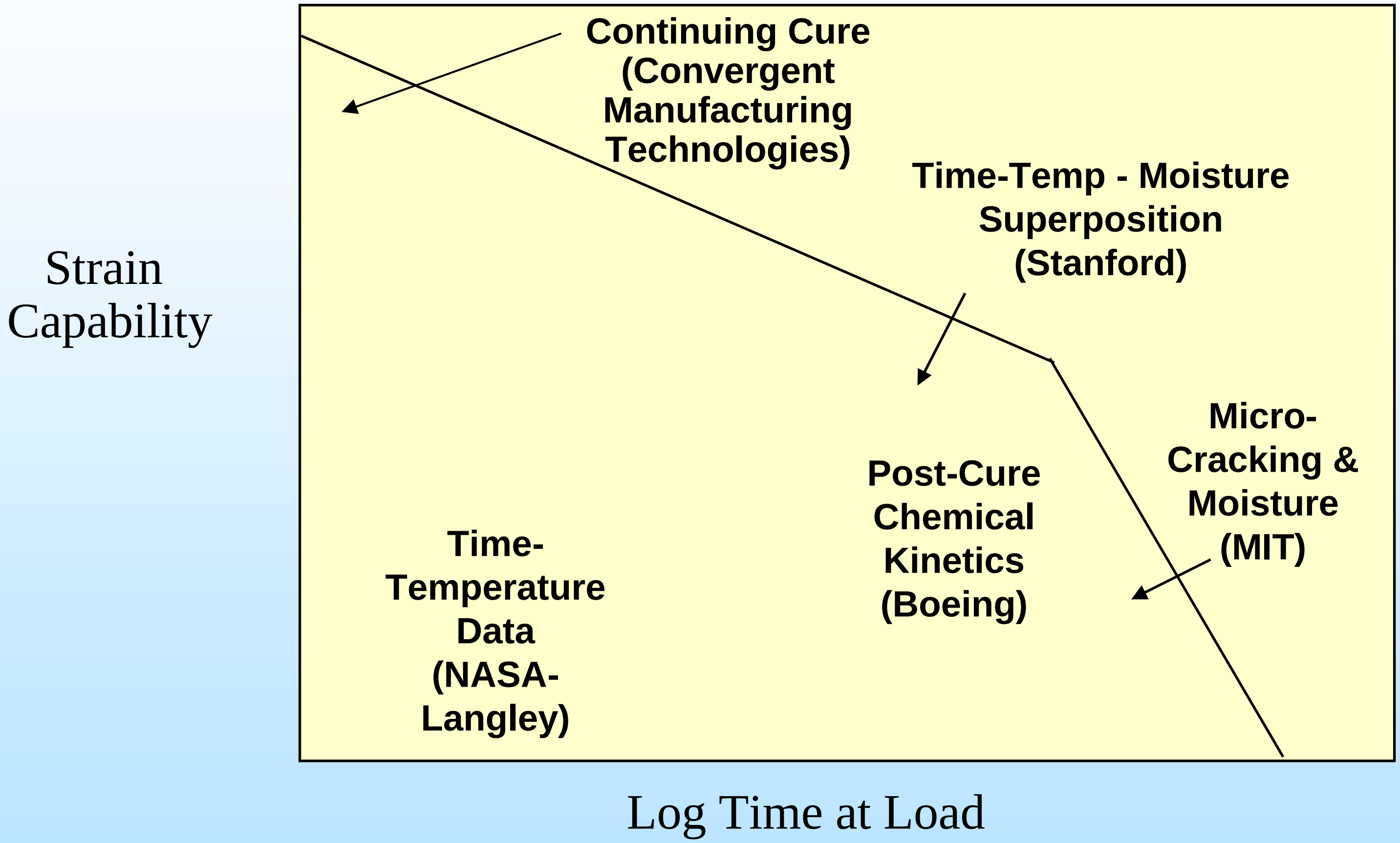
Producibility Indirect Support Materials

- Prepreg
  - Backing
  - Separator
- Cutting
  - Separator
- Layup
  - Separators
  - Shop Aid Tools
- Debulking
  - Separators
  - Breathers
  - Bleeders
  - Bagging
- Cure
  - Separators
  - Breathers
  - Bleeders
  - Bagging
- Tooling
  - Mold Release



- Warnings if indirect support materials not evaluated
- Flags Concerning Lack of Conformance

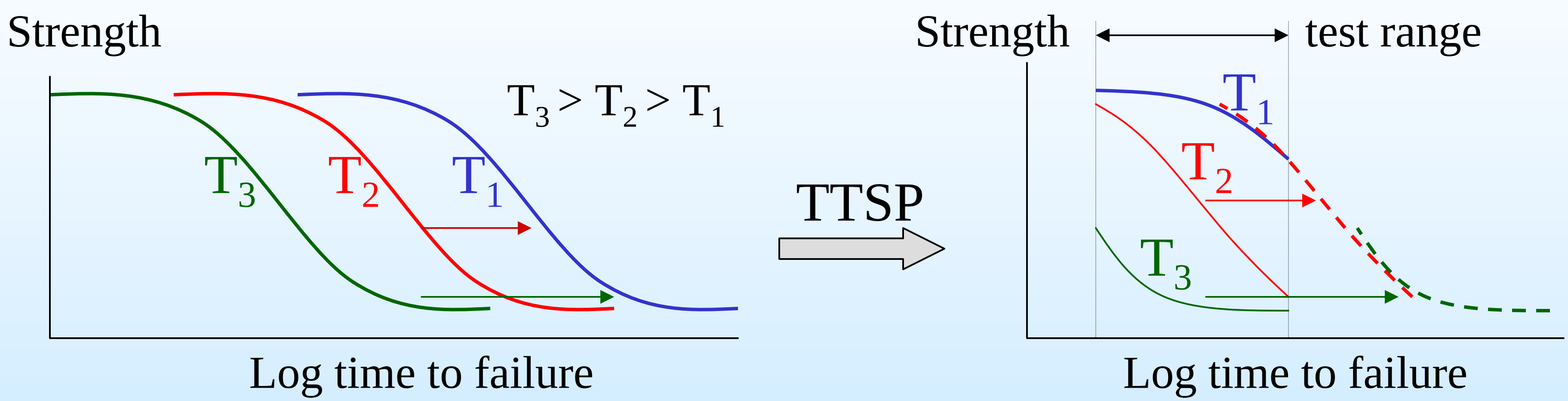
Knowledge Management and Feature Based Studies: End of Life Properties



This Approach Predicts the Effects of Four Competing Failure Modes – Time, Temperature, Environment and Chemical Degradation

Knowledge Management & Feature Based Studies: End of Life Properties

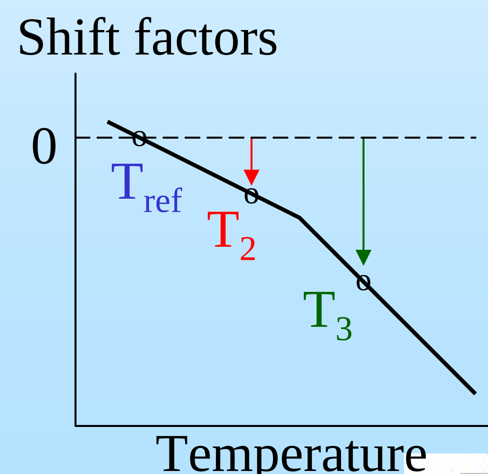
Assumption: Same shape for any temperature = Master Curve



Curves can be superposed by horizontal shifts

⇒ Master curve can be generated from the fragments of curves at different temperatures

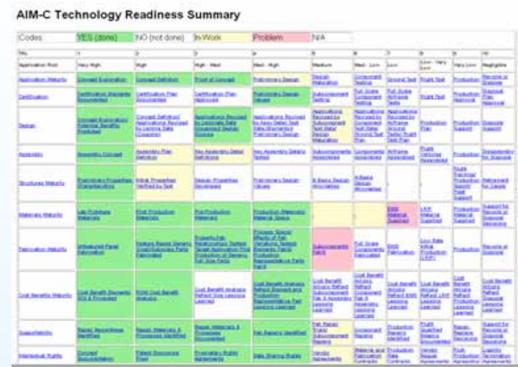
⇒ Accelerated evaluation of long term performance



What about major obstacles to insertion?

Define and Address Scale Up Issues
Assess and Validate End of Life Properties
Understand the Drivers of Part Geometry and Manage Them
Plan Maturation Cycles and Eliminate Unplanned Rework
Facilitate Transition and Support Via Well-Documented Knowledge Base

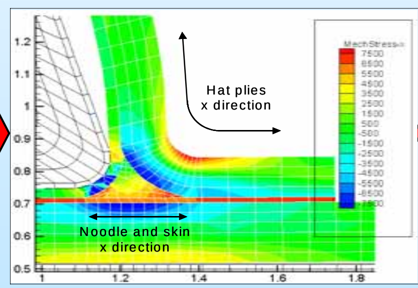
How Do I Accelerate Technology Insertion?



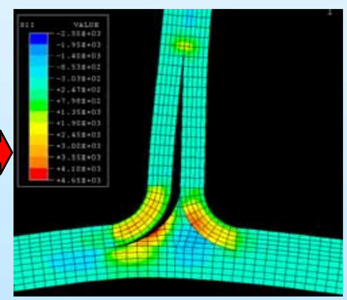
Use Methodology Document or Software Interface For Thorough Assessment of All Requirements

Assessment and Maturity Status

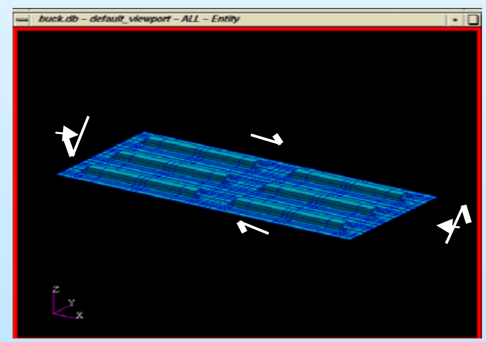
Analytical Models From Constituents



To Processing



To Effects of Defects



To Structures

To Provide Analysis Supported by Test To Accelerate Readiness

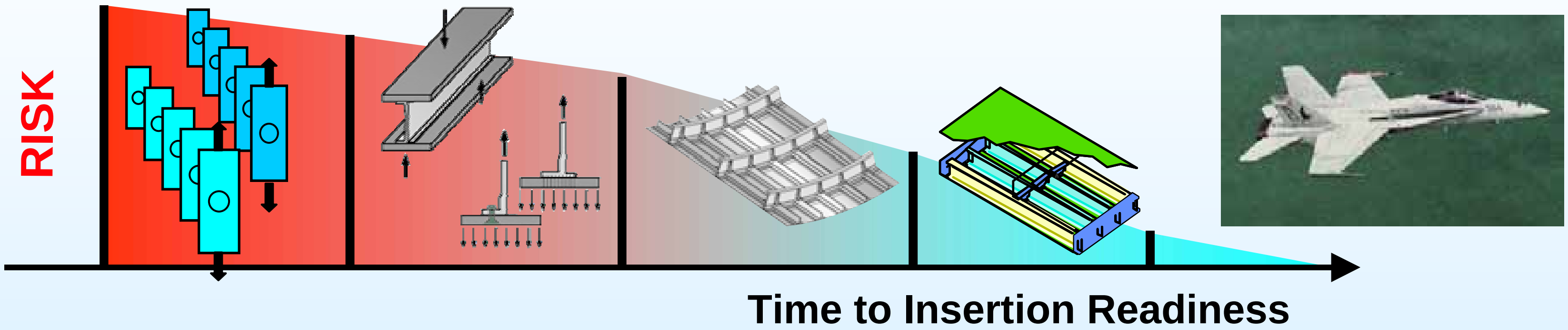
Accelerated Insertion of Materials Is Achieved in AIM-C Methodology by

- Development and characterization focused on design knowledge base needs.
- Coordinated use of
  - Existing Knowledge
  - Validated Analysis tools
  - Focused Testing
- Use of Physics Based Material & Structural Analysis Methods
- Use of Integrated Engineering Processes & Simulations
- Uncertainty Analysis and Management
  - Early Feature Based Assessment/Demonstration
  - Tracking of Variability and Error Propagation Across Scales
- Rework Acknowledgement and Avoidance
- Disciplined approach for pedigree management

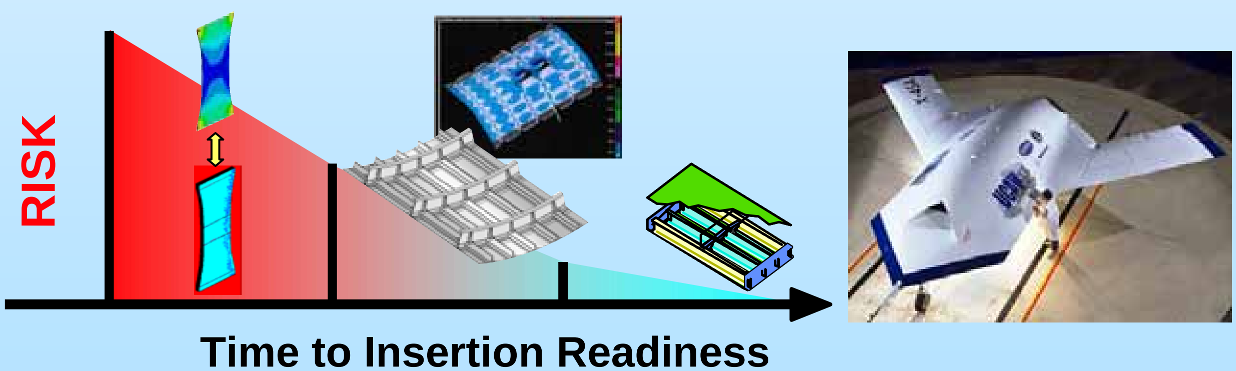
Orchestration to efficiently tie together the above elements to a design knowledge base for qualification and certification.

What's the Benefit of Integrated Assessment, Development, and Characterization?

Traditional Test Supported by Analysis Approach



AIM Provides an Analysis Approach Supported by Experience, Test and Demonstration



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